Review Article

Systematic review on the association of abdominal obesity in children and adolescents with cardio-metabolic risk factors

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Background: The adverse health effects of abdominal obesity are well documented in adults, but such association remains to be determined in the pediatric age group. This study aims to perform a systematic review on the association between abdominal obesity and cardio-metabolic factors such as dyslipidemia, hypertension, and hyperglycemia among children and adolescents. **Materials and Methods:** A systematic literature search was conducted using PubMed, Scopus and Google Scholar databases to May 2014. Two independent reviewers identified relevant papers in several steps. After studying the titles and texts of documents, repeated and irrelevant ones were excluded. The search was refined to the English language. We did not consider any time limitation. Studies with different measuring methods of abdominal obesity were included. Studies with abdominal obese patients secondary to other disease were excluded from the study. In final, the data of association of cardio-metabolic risk factors and abdominal obesity extracted from studies. **Results:** Overall, 3966 articles were reviewed, and 61 of them were studied according to the inclusion and exclusion criteria. Waist circumference (WC), waist-to-height ratio, and waist-to-hip ratio were the most common indexes used for defining abdominal obesity. The association of high blood pressure with increasing WC was seen in several studies. The association of other cardio-metabolic risk factors was seen in some studies. **Conclusion:** Whatever the definition used for abdominal obesity and whatever the methods used for anthropometric measurements, central body fat deposition in children and adolescents increases the risk of cardio-metabolic risk factors. Therefore, more attention should be paid to abdominal obesity of children and adolescents both in clinical practice and in epidemiological studies.

Key words: Cardio-metabolic risk factors, central fat deposition, obesity, pediatric age group

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INTRODUCTION

The prevalence of overweight/obesity has increased worldwide; affecting all age ranges including the pediatric population. Childhood obesity has been increasing at an alarming rate in both developed and developing countries.[1-3] In all age ranges, obesity is associated with several adverse health effects as hypertension, dyslipidemia, insulin resistance and type-2 diabetes, as well as social and psychological problems.[4] Approximately, 60% of those who present obesity in the first decades of life will have at least one of the abovementioned metabolic alterations in adulthood.[5]

Obesity in childhood is associated with adverse cardio-metabolic risk factors, including elevated blood pressure (BP), triglycerides (TG), total and low density lipoprotein cholesterol (LDL-C) and insulin, as well as reduced high density lipoprotein cholesterol (HDL-C),[6,7] and in turn with obesity and cardiovascular disease (CVD) in adulthood.[8]

In addition, childhood obesity is a risk factor for atherosclerosis and is associated with increased mortality due to CVD in adulthood, independent of adult weight.[9,10]

Individuals with upper body obesity are more susceptible to cardio-metabolic risk factors. Most studies have been conducted in adults, and limited experience exists in the pediatric age group. The Bogalusa Heart Study showed that the distribution of central fat determined by waist circumference (WC) at the ages of 5-17 years is associated with abnormal concentrations of TG, LDL-C, HDL-C, and insulin.[11] Central obesity is a major clinical and public health issue. Compared with generalized obesity, central obesity is more strongly correlated with metabolic risk factors. A number of studies have

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shown that central obesity is an independent risk factor for type 2 diabetes mellitus, dyslipidemia, systemic arterial hypertension, and coronary artery disease.[12,13] In adults, the risk of cardiovascular death, myocardial infarction, and all-cause death increases in parallel with WC.[14]

Although childhood obesity is a well-recognized risk factor for developing CVD and type 2 diabetes mellitus in adulthood, excess central (intra-abdominal) body fat distribution may be more related to these diseases than peripheral distribution.[15]

It is important to identify children who are at increased risk of developing comorbidities associated with obesity, to potentially intervene and prevent the development of chronic diseases including type 2 diabetes and CVD. However, the association of abdominal obesity in children and adolescents with cardio-metabolic risk factors remain controversial.[17-19] This paper aims to perform a systematic review on papers that studied the association between abdominal obesity and cardio-metabolic factors among children and adolescents.

MATERIALS AND METHODS

Literature search

The search was conducted using PubMed, Scopus and Google Scholar databases to May 2014. The following keywords were used: ["Child"[Mesh] OR "Adolescent"[Mesh]) AND ("Obesity"[Mesh] OR "Pediatric Obesity"[Mesh] OR "Ideal Body Weight"[Mesh] OR "Overweight"[Mesh]) AND ("Obesity, Abdominal"[Mesh]) AND ("Dyslipidemias"[Mesh] OR "Hyperlipidemias"[Mesh] OR "Hypercholesterolemia"[Mesh] OR "Hypertension"[Mesh] OR "Hyperglycemia"[Mesh].

The search was refined to the English language. We did not consider any time limitation. The flow chart of the study selection process is presented in Figure 1.

Titles and abstracts of papers were screened and relevant papers were selected. Duplicates were removed. Then, full texts of relevant papers were read, and findings were rescreened. To increase sensitivity and to select more studies, the reference list of the published studies was checked. Two independent reviewers (MK and HN) screened the titles and abstracts of papers, which were identified by the literature search, for their potential relevance or assessed the full text for inclusion in the review. In the case of disagreement, and the discrepancy was resolved in consultation with an expert parbitrating investigator (RK).

Selection criteria

All studies among children and adolescents, which evaluate the association of abdominal obesity or general obesity or overweight with cardio-metabolic risk factors were included the review. Studies with different measuring methods of abdominal obesity were included. Studies with abdominal obese patients secondary to other disease were excluded from the study.

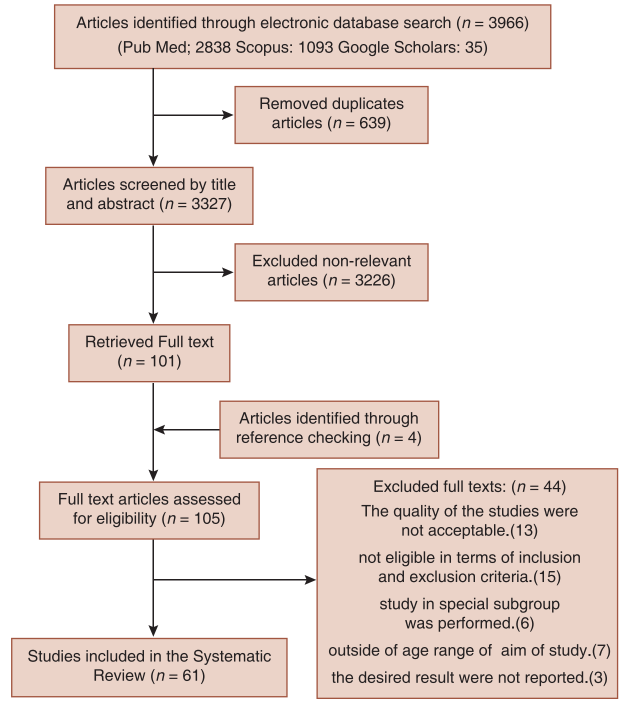

Figure 1: Papers search and review flowchart for selection of primary study

Data extraction and abstraction

Two reviewers abstracted the data independently. The required information that was extracted from all eligible papers was as follows: Data on first author's last name, year of publication and country of the study population, population studied, aim and findings of studies.

RESULTS

Study selection strategy

As presented in Figure 1, from 3966 articles from the primary search, 61 studies were included in the current study.

Study characteristics

Papers were published between the years 2001 and 2013. The age of participants of included studies ranged from 6 to 18 years.

WC, waist-to-height ratio (WHtR), waist-to-hip ratio (WHR), trunk-to-appendicular fat ratio, WC to arm circumference, DXA-trunk fat, preperitoneal fat thickness, suprailiac skinfold thickness were the anthropometric indexes that were used to measure abdominal or central obesity or central fat distribution. WC, WHtR, and WHR were the

Table 1: Characteristics and main findings of studies included in this systematic review are presented

Reference	Location	Population studied	Type of study	Aims	Findings
Colín-Ramírez *et al.*[16]	Mexican	Mexican school-aged children	Cross-sectional	To determine the anthropometric, physical activity and dietary factors associated with both systolic and diastolic hypertension	DBP and WC were positively and significantly related to the presence of systolic hypertension. An adjusted OR of 1.06 (95% CI=1.01-1.11) for systolic hypertension per increase of 1 cm in waist diameter was found
Maffeis *et al.*[17]	Italy	Italian children (740 boys and 739 girls, *n*=1479), ranging from 5 to 15 years of age	Cross-sectional	To determine whether using a combination of BMI and WC or WHtR is clinically helpful in identifying children with high metabolic and cardiovascular risks	SBP was significantly different between the two waist categories at normal weight. WC correlated positively with SBP and DBP, plasma triacylglycerol and fasting glucose but negatively with HDL-C
Hirschler *et al.*[18]	India	933 Indian children mean age 9.47 (2.06) and 10.68 (2.91) in two groups	Cross-sectional	To compare the prevalence of cardiovascular disease risk factors in Indian children and to examine BMI, WC, and WC/height as predictors of dyslipidemia in both groups	Area under the ROC curve was significantly different from 0.5 in WC in BA children (indicating that WC was acceptable predictors for high TG but the AUC was not significantly different in WC in SAC children for high TG, indicating that these two anthropometric measures were not acceptable predictors for this variable
Benmohammed *et al.*[19]	Algerian	305 adolescents (133 boys and 172 girls) aged 12-19 years	Cross-sectional	Estimate the prevalence of hypertension in Algerian overweight and obese adolescents to assess the risk factors associated with hypertension and an increase in arterial stiffness	WC ratios were significantly higher in hypertensives than in normotensives. The risk of hypertension was also significantly higher in boys and associated with WC, independent of age and severity of weight excess (whether overweight or obese)
Valerio *et al.*[20]	Italia	T1DM adolescents (*n*=412, age: 17.3-0.9 years)	Cross-sectional	To analyze the prevalence of abdominal adiposity and other traditional risk factors for cardiovascular disease in a large sample of Italian adolescents with T1DM	Insulin dose per body surface significantly correlated with waist only in females
Maffeis *et al.*[21]	Italia	1044 Italian overweight and obese children (484 males and 560 females) between the ages of 6 and 11 years	Cross-sectional	Assess the relationship between BP, indexes of adiposity, body fat distribution and IR	In bout sex, SBP and DBP correlated with WC. Logistic regression analysis showed that waist or WHtR, adjusted for age and pubertal stage, was able to predict HBP in obese boys and girls
Gopinath *et al.*[22]	Australia	1294 children ages 3-6 years	Cross-sectional	Association between BMI, WC, and BP among preschool-aged children	Each unit increase in WC was associated with a 0.14 and 0.23 mmHg increase in SBP and DBP, respectively
Griz *et al.*[23]	Brazil	1824 students from 29 public schools, aged from 14 to 20 years	Cross-sectional	To determine the prevalence and association of CO and hypertension and its associations with alcohol intake, smoking and physical activity in adolescents	The probability of hypertension increases if the subject is male, has a WC □90, WC □75 and does not practice physical activity
Kromeyer-Hauschild *et al.*[24]	Germany	3492 boys and 3321 girls aged 11-17 years	Cross-sectional	Compare the fixed 0.5 cut-off and the age - and sex specific 90th percentile (P90) for WHtR in German adolescents with respect to the prevalence of abdominal obesity and to compare the screening ability of WHtR and BMI to identify hypertensive BP values	Moderate positive correlation in both sex between WHtR-for-age and age-, sex-and height adjusted SBP and DBP (*Z* scores) (SBP r=0.296 and 0.183, DBP r=0.141 and 0.065 in boys and girls, respectively; P<0.001)
Ribas and Santana da Silva[25]	Brazil	874 subjects between the ages of 6 and 19 years	Cross-sectional	To evaluate which of the currently applied obesity parameters (the BMI, the percentage of body fat, the WC and the upper arm fat area) can predict the risk for dyslipidemia in Brazilian children and adolescents	There was a marginally significant (P=0.04) relationship between the WC and the TC. Individuals with elevated WC showed a positive correlation with alterations in the lipid profile. After adjusting for age and income, a BMI above the 85th percentile and an elevated percentage of body fat were the variables most strongly associated with dyslipidemia in the youngest subjects
Kouda *et al.*[26]	Japan	401 5th grade children who attended elementary school in Hamamatsu, Japan	Cross-sectional	Relationship between BP and the ratio of central fat measured on dual-energy X-ray absorptiometry (DXA) in childhood	In boys, the trunk-to-appendicular fat ratio was significantly related to SBP and DBP after adjusting for confounding factors such as height and pubic hair appearance. In addition, an increase in trunk-to-appendicular fat ratio was related to an increase in BP after adjusting for confounding factors including whole body fat volume and trunk fat volume. The relationship between fat distribution and BP was not observed in girls

(*Continued*)

Table 1: (Continued)

Reference	Location	Population studied	Type of study	Aims	Findings
Chen and Li[27]	China	939 3-6-year-old preschool children	Cross-sectional	To investigate the relationship between WC and BP to determine if WC was an indicator of BP in preschool children	WC was independently associated with HBP in boys aged 3-6 years. In addition to BMI, increased WC was found to be an indicator of HBP in the preschool children, especially in boys
Plourde[28]	Canada	Adolescents aged between 13 and 15 years old	Case-control	If type of fat distribution is associated with glucose and lipid profile abnormalities	WC: AC, CPR, STR and SUM are stronger predictors of both glucose and lipid profiles than BMI. (WC: AC ratio of WC to arm circumference was used as an indicator of a central pattern of adiposity. Two other indices of central adiposity were calculated from skinfolds: CPR as subscapular skinfold + suprailliac skinfold)/(triceps skinfold + thigh skinfold) and ratio of STR skinfold. The SUM was calculated from triceps, subscapular, suprailliac and thigh skinfolds. SUM provides a single measure of subcutaneous adiposity)
Hu *et al.*[29]	China	1145 Chinese children and adolescent (608 male, 537 female)	Cross-sectional	Compared the association between BP and obesity	The prevalence of high SBP and DBP increased directly with corresponding increments in BMI, WC and WHtR, although the prevalence and OR of HBP were higher when increased BMI was combined with WC (OR=3.39; 95% CI=1.79-6.41) or WHtR (OR=3.28; 95% CI=1.71-6.30)
Da Silva and Rosa[30]	Brazil	706 children mean age 11.6	Cross-sectional	To evaluate the association between the average levels of BP with nutritional state – BMI, BFP, WC – and with their socialeconomic state	BMI and WC presented a regular correlation with SBP and weak with DBP. multiple linear regression showed a higher variation percentage of SBP (27.9%) when there is an interaction with the WC indicators and BMI (*r*=0.27)
Adegboye *et al.*[31]	Denmark, Estonia and Portugal	2835 children in the 3rd (8.2-11.3 years) and 9th (14-17.3 years)	Cross-sectional	To evaluate the ability of BMI and fat location indices to predict clustering of risk factors for cardiovascular and metabolic disorders in children and adolescents	In this study, BMI, WC and WHtR were useful in identifying children at risk, but in the present study WC did not perform better than BMI in identifying children with a clustering of risk factors. BMI and WC performed better than WHtR in detecting children with □3 RF in boys, only
Juárez-Rojas *et al.*[32]	Mexico	770 male and 1076 female students (12-16 years old) from eight randomly selected high schools in Mexico City	Cross-sectional	To determine the prevalence of HBP and associated cardiovascular risk factors	A stepwise multiple regression analysis showed that waist (18.3%) accounted for 26% of the variance in SBP; whereas waist (0.4%) accounted for 15.9% of the variance in DBP
Freedman *et al.*[11]	Louisiana	Children aged 5-17 years (*n*=2498) in the Bogalusa Heart Study	Cross-sectional	Relation of the BMI-for-age *Z* score and WHtR to risk factors (lipids, fasting insulin, and BPs)	WHtR was slightly better (0.01-0.02 higher R2 values, *P*<0.05) in predicting concentrations of total-to-HDL-C ratio and LDL-C
Ghosh and Bandyopadhyay[33]	India	197 girls aged 5-16 years	Cross-sectional	Evaluate the relationship of general and central adiposity measures with hypertension and to find out the best adiposity measure in predicting hypertension	Both WC (OR=2.20, 95% CI=1.32-3.69) and CI (OR=1.85, 95% CI=1.14-3.0) were significantly associated with hypertension. However, there was no significant association in BMI and WHR with hypertension
Ribeiro *et al.*[35]	Brazil	1403 students, aged from 6 to 18 years	Cross-sectional	To verify an association, if it exists, between obesity and BP raised beyond the 90th percentile in children and adolescents, and to determine the measure of adiposity that best correlates with BP in these subjects	When all covariates implicated in this association, such as age, race, and socioeconomic standing, along with the other measurements of adiposity, were added to the model, the only remaining predictor of HBP proved to be the BMI. Analysis of neither the WC, nor the ratio of circumferences at the waist and hip, revealed any materially significant association
Pausova *et al.*[36]	Canada	A population-based sample of adolescent boys (*n*=237) and girls (*n*=262), age 12-18 years	Cross-sectional	To investigate association of body fat deposited viscerally rather than elsewhere in the body with hypertension	In boys, BP was strongly positively associated with VF (*P*<0.0001), whereas it was less strongly and negatively associated with TBF (*P*=0.004); in contrast, in girls, BP was strongly positively associated with TBF (*P*=0.0006), whereas it was not associated with VF (*P*=0.08)

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Table 1: (Continued)

Reference	Location	Population studied	Type of study	Aims	Findings
Guimarães *et al.*[37]	Brazil	536 adolescents aged between 11 and 18 years	Cross-sectional	To evaluate the effect of BMI and WC on BP of adolescents	High SBP and DBP were 3.9 and 3.4 times more frequent among boys and 2.2-2.0 times more frequent among girls with WC >75th *P*, respectively. Using simple linear regression analysis, each increment in BMI would increase SBP by 1.198 mmHg, and in WC by 0.622 mmHg
Graves *et al.* 2014[38]	UK	2858 adolescents aged 15.5 (SD=0.4) years and 2710 of these participants as children aged 7-9 years were used in this analysis	Secondary data analysis of population based cohort	To examine the associations between BMI and WHtR measured in childhood and adolescence and cardio-metabolic risk factors in adolescence	Both BMI and WHtR measured at ages 7-9 years and at age 15 years were associated with cardiometabolic risk factors in adolescents. A WHtR □0.5 at 7-9 years increased the odds by 4.6 (95% CI=2.6-8.1) for males and 1.6 (0.7-3.9) for females of having three or more cardiometabolic risk factors in adolescence. Cross-sectional analysis indicated that adolescents who had a WHtR □0.5, the OR of having three or more cardiometabolic risk factors was 6.8 (4.4-10.6) for males and 3.8 (2.3-6.3) for females. The WHtR cut-point was highly specific in identifying cardiometabolic risk co-occurrence in male children and adolescents as well as female children (90%-95%), but had poor sensitivity (17%-53%)
Kovacs *et al.*[39]	Hungary	3678 students, (1849 boys and 1829 girls), age between 6.5 and 15.5	Cross-sectional	To evaluate the role of WC in identification of children with HBP	SBP was higher in children with abdominal obesity compared with those with normal WC ($P<0.01$) both in normal and in overweight BMI categories. Similar results were found for DBP in normal weight girls ($P=0.032$) and overweight boys ($P=0.04$). WC was significantly correlated with SBP and DPB in all BMI categories, even after adjustment for age and BMI. Despite these findings, no significant OR of prehypertension or hypertension for abdominal obesity was found in the normal weight category. On the contrary, in overweight children, prevalence of prehypertension (OR=1.42 [1.1; 1.8]) and hypertension (OR=1.35 [1.1; 1.7]) was higher among abdominal obese children. Similarly, the prevalence of prehypertension was almost two-times higher among obese children with abdominal obesity (11.8% vs. 22.5%); however, no significant OR was found
He *et al.*[40]	China	A total of 148 healthy prepubertal boys (age range, 3-11 years) and 99 girls (age range, 3-10 years) were studied	Cross-sectional	Investigate the body fat distribution pattern in prepubertal Chinese children and to investigate the relationship between central fat distribution and specific biomarkers of cardiovascular disease	Insulin and TG were positively related to central fat measured by DXA-trunk fat ($P<0.05$) but not related to the WC. In BP model, WC was a significant predictor of both SBP and DBP, while DXA-trunk fat was associated with DBP only
Hacihamdioglu *et al.*[41]	Turkey	One-hundred four obese children (9.3±2.5 years) and 30 healthy age-matched control subjects were enrolled in the study	Case-control	Investigate carotid IMT in obese children and evaluate the relationship of IMT to various cardiovascular risk factors	Significant positive correlations were found between increased carotid IMT and BFP, BMI, age, height, SBP, WC, SFT, TG and insulin levels, and IR index. In a linear logistic regression analysis, the only parameter affecting the increase in carotid IMT was WC (β: 0.589, $P<0.001$)
Khoury *et al.*[42]	Canada	3248 (14-and 15 years old) students	Cross-sectional	To determine if the interaction of WC percentile and WHtR with BMI may serve to provide further risk specification in the lipid and BP assessment of adolescents beyond BMI classification	The associations between BP, lipid profile, and measures of adiposity (BMI alone, BMI/WC percentile, and BMI/WHtR) were statistically significant but had a limited strength and were not statistically significant from each other. For overweight and obese subjects, increased WHtR categories were associated with worsened lipid profile and increased odds of hypertension both relative to subjects with both normal BMI and normal WHtR and subjects with normal WHtR within each BMI category

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Table 1: (Continued)

Reference	Location	Population studied	Type of study	Aims	Findings
Genovesi *et al.*[43]	Italia	4177 school children age 5-11 years old (2005 [48%] girls and 52)	Cross-sectional	To investigate the ability of BMI and WC, single and combined, in identifying children who are at risk of hypertension and in influencing absolute BP values	Only BMI and WC showed a remarkable ability at discriminating hypertensive children (AUC, 0.84 and 0.76, respectively). The multivariate analysis showed that *Z* scores for both BMI and WC were significantly related to the risk of hypertension with OR of 3.59 (95% CI=2.55-5.06) and 1.20 (95% CI=1.04, 1.39), respectively, after adjusting for sex and age. When the weight class was included in the multivariate analysis, WC retained its ability to identify hypertensive children only in the obese class (OR=1.44; 95% CI=1.21-1.72; $P<0.01$). When considering BP as a continuous variable, both weight class and WC showed a significant effect on SBP and DBP absolute values ($P<0.01$). WC effect on BP values was maintained even when corrected for BMI
Turconi *et al.*[44]	Italia	Five hundred and thirty-two adolescents of both sexes, aged 15-4 (SD=0-7) years	Cross-sectional	Investigate BP levels and their relationship with different indices of body fat in a group of adolescents, in order to evaluate the prevalence of hypertension and plan preventive and corrective strategies	In linear correlation analysis, BMI and all adiposity indices, except WHR, were found to be significantly associated (*P* ranging between 0.05 and 0.001) with both SBP and DBP in both sexes, with *r* ranging between 0.152 and 0.359. Multiple regression analysis with the stepwise method showed BMI and body fat mass to have the strongest association ($P=0.001$) with BP, with *r* ranging between 0.275 and 0.359
Rosini *et al.*[45]	Brazil	Students ($n=1011$; aged 6-14 years)	Case-control	Evaluated the use of WC measurements to detect hyperglycemia and dyslipidemia in children and adolescents using the WC cut-off points reported in the Bogalusa Heart study and the New Zealand study	In general, children with increased WC exhibited higher concentrations of TC, TG, LDL-C, and nonHDL-C and lower levels of HDL-C. The AUC of the WC measurements were 0.770 (95% CI=0.744-0.797) and 0.600 (95% CI=0.569-0.631) using, respectively, the New Zealand and Bogalusa cut-off points for WC, indicating the prediction of simultaneous hyperglycemia, increased levels of nonHDL-C, and reduced HDL-C for students with increased WC Logistic regression analysis revealed that increased WC was associated with simultaneous hyperglycemia and dyslipidemia after controlling for differences in sex and age ($P<0.01$ for all)
Moser *et al.*[46]	Brazil	1441 students from public schools, aged from 10 to 16 years (655 boys and 786 girls)	Cross-sectional	To investigate the association of BP and BMI, WC, WHtR and triceps skinfold, in children and adolescents	In multivariate analysis, only BMI (OR=2.9; 95% CI=1.9-4.5) and triceps skinfold (OR=1.9; 95% CI=1.3-3.1) were found as predictors of HBP, regardless of abdominal adiposity, sexual maturation and socioeconomic status. WC, WHtR, sexual maturation, and socioeconomic status were not associated with risk of HBP
Botton *et al.*[47]	French	452 children (235 boys and 217 girls) aged 8-17 years	Cross-sectional	Report the prevalence of high levels of cardiovascular risk factors in association with overweight and second aim was to assess, for the first time separately in boys and girls, whether cardiovascular risk factors are associated with children's abdominal fat mass independently of subcutaneous fat mass, as already shown in adults	After adjusting for the sum of skinfolds, an independent association between the risk factors and WC was found in girls. In girls, abdominal fat distribution is associated with cardiovascular risk factors, independently of overall adiposity
Tadokoro *et al.*[48]	Japan	374 Japanese high school students aged 15-16 years (193 boys and 181 girls)	Cross-sectional	To investigate the factors the influence visceral fat accumulation in adolescent	There was a positive correlation between PFT and ALT, TG, uric acid and leptin levels, and negative correlation with HDL-C were observed in boys. There was also positive correlation between PFT and leptin, and negative correlation with HDL-C and adiponectin in girls. Multivariate regression analysis was shown that leptin and TG independently associated with PFT in boys, and leptin was independently associated with PFT in girls. Boys with visceral obesity had significantly higher value for ALT, TC and lower HDL-C levels

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Table 1: (Continued)

Reference	Location	Population studied	Type of study	Aims	Findings
Mokha *et al.*[6]	USA	3091 black and white children (56% white, 50% male), 4-18 years of age	Cross-sectional	Utility of WHtR in assessing the status of abdominal obesity and related cardiometabolic risk profile among normal weight and overweight/obese children, categorized according to the accepted BMI threshold values	On multivariate analysis the normal weight centrally obese children were 1.66, 2.01, 1.47 and 2.05 times more likely to have significant adverse levels of LDL-C, HDL-C, TG and insulin, respectively. In addition to having a higher prevalence of parental history of T2DM, the normal weight CO group showed a significantly higher prevalence of MS (P<0.0001). In the overweight/obese group, those without CO were 0.53 and 0.27 times less likely to have significant adverse levels of HDL-C and HOMA-IR, respectively (P<0.05), as compared to those with CO. These overweight/obese children without CO also showed significantly lower prevalence of parental history of hypertension (P=0.002), T2DM (P=0.03) and MS (P<0.0001)
Juárez-López *et al.*[49]	Mexico	466 obese children and adolescents between 11 and 13 years of age	Cross-sectional	Assess the association between the degree of IR and the different components of the MS among obese children and adolescents	WC begins to be significant from the 25th percentile of IR (P=0.014). From the 50th percentile onwards, in addition to WC, also DBP, glucose and TG become significant (P<0.05). Above the 75th percentile, all of the OR are significant (P<0.05), except SBP and DBP. In all of HOMA-IR percentile 25-49.9 (2.4-3.3), 50-74.9 (3.4-4.9) and □75 (□5.0) the WC was significant
Abolfotouh *et al.*[50]	Egypt	1500 adolescents (11-19 years)	Cross-sectional	Investigate the relationship between HBP and obesity	HBP was significantly associated with overall obesity based on BMI (OR=2.18, 95%, CI=1.38-3.44) and CO based on WC (OR=3.14, 95%, CI=1.67-5.94)
Schommer *et al.*[51]	Brazil	511 adolescents were studied in six schools. Their mean age was 12.57 years, and 55.2% (n=282) were females	Cross-sectional	Study the association between anthropometric variables and BP levels in school children from the 5th to 8th grades, and to identify which parameter was more strongly correlated with BP levels	Among the anthropometric variables analyzed, hip circumference was the one with the strongest correlation with increased BP (r=0.462, P<0.001), followed by WC (r=0.404, P<0.001) and abdominal skinfold (r=0.291, P<0.001)
Zhang and Wang[52]	China	38,822 students (19,456 boys and 19,366 girls) aged 7-17 years	Cross-sectional	Comparison the BP levels among children and adolescents with different BMI and WC	Within each BMI categories (normal weight, overweight, and obesity), children and adolescents with WC C P90 had higher BP levels than those with WC\P90 (P\0.01). When BMI and WC were combined, the highest and lowest prevalences of relatively HBP were noted in obese with WC C P90 group (54.52% for boys and 48.71% for girls) and normal weight with WC\P90 group (17.00% for boys and 14.13% for girls). Children and adolescents with high BMI and high WC might have an increased risk of elevated BP. Our results suggest that the additional measurement of WC is better than BMI alone to help identify HBP risks
Lu *et al.*[53]	China	1665 Han adolescents aged 13-15 years	Case-control	Evaluate the relationship between WHtR and glucose and lipid metabolism	Compared with the control group (n=1340, WHtR <0.46), the abdominal obesity group (n=325, WHtR=0.46) had significantly higher levels of BMI (26.3±3.6 vs. 18.9±2.3), WHtR (0.51±0.04 vs. 0.40±0.03), FPG (4.99±0.48 vs. 4.86±0.46), and TG (1.21±0.62 vs. 0.87±0.41), and a lower level of high-density lipoprotein cholesterol (1.26±0.27 vs. 1.46±0.30) (P<0.01). Logistic regression analysis showed that after controlling for age, sex and BMI, the elevated FPG and dyslipidemia risk OR of the abdominal obesity group were 1.954 (95% CI=1.250-3.054) and 2.012 (95% CI=1.204-3.362) (P<0.01) respectively. When clustered, the OR of elevated FPG and dyslipidemia was 6.659 (95% CI=1.337-33.159) (P<0.01)
Mirkopoulou *et al.*[54]	Greece	One hundred adolescents (17 years of age)	Case-control	Assess the diet and metabolic parameters of a rural sample of adolescents	CO increased the chances of IFG (OR=8.000, CI=1.6-39.1) and doubled the prevalence of dyslipidemia (OR=2.190, CI=0.5-9.1). Abdominal obesity increased the chances for IFG 8-fold (OR=8.000, CI=1.6-39.1), as well as for high TG (OR=2.190, CI=0.5-9.1) and serum cholesterol levels (OR=2.167, OR=0.3-15.6)

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Table 1: (Continued)

Reference	Location	Population studied	Type of study	Aims	Findings
Hashemipour *et al.*[55]	Iran	929 obese children and adolescents aged 6-18 years	Retrospective study	Aimed to assess the association between these anthropometric indices and dyslipidemia in obese children and adolescents	There was a significant association between TC, LDL-C, TG and FBS with BMI, WC, WHR and WSR. Moreover, ROC diagrams showed that in boys, the most significant association was between BMI with LDL-C and TC and also between WC and TC in addition to WSR and TC and LDL-C in the age group of 10-14 years. Based on ROC diagrams, the most AUC for girls was between WSR, BMI and WC with TG in 10-14 years age group. In the age groups of 6-9.1 years, there was a significant correlation between WC and TG and in the age group of 14-18 years there was a significant correlation between WSR and LDL
Senbanjo and Oshikoya[56]	Nigeria	423 adolescents with ages ranging from 10 to 19 years	Case-control	To determine prevalence of general and CO and their relationship with BP levels among adolescents	With simple linear regression analysis, BMI and WC explained 10.7 and 8.4%, respectively of the variance in SBP, and 3.6 and 2.7%, respectively of the variance in DBP. The correlation coefficient of BMI with SBP was higher than that of WC with SBP (0.327 vs. 0.29). Similarly, the correlation coefficient of BMI with DBP was higher than that of WC with DBP (0.189 vs. 0.129). There was a significantly higher prevalence of high SBP among male children with general obesity (χ^2=36.5, P<0.001). Among the children with CO, a significantly higher prevalence of high SBP (χ^2=22.3, P<0.001) and high DBP (χ^2=4.1, P<0.042) was seen in only the males. In a simple linear regression analysis, BMI and WC explained 10.7 and 8.4%, respectively of the variance in SBP, and 3.6 and 2.7%, respectively of the variance in DBP. Each increment in BMI increased SBP and DBP by 0.327 and 0.189 mmHg, respectively, while each increment in WC increased SBP and DBP by 0.29 and 0.164 mmHg, respectively. When the effects of BMI and WC on BP were studied in a multiple logistic regression equation model [Table 4], BMI was significantly associated with high SBP (OR=0.8, 95% CI=0.65-0.99, P<0.05)
Fernandes *et al.*[57]	Brazil	1145 adolescents, from 11 to 17 years old (536 of the male sex and 609 of the female)	Cross-sectional	To prepare critical values for the WC and to analyze its efficiency in indicating increased values of the arterial pressure	Independently of the gender and age group, there was a significant relation between the WC values and all the adiposity indicators adopted in the study
Casonatto *et al.*[58]	Brazil	656 adolescents with age ranging from 10 to 13 years old	Cross-sectional	To analyze the association between abdominal obesity and HBP among adolescents	Association between abdominal obesity and HBP was present in both genders (PR=2.7; 95% CI=1.8-4.2). Abdominal obesity was associated with higher BP independently of age
Christofaro *et al.*[59]	Brazil	1021 adolescents aged 10-17 years	Cross-sectional	To investigate the association between general and abdominal obesity with HBP and to identify the sensitivity and specificity of these indicators to detect HBP in adolescents	For both genders, OR for HBP was higher in abdominal obesity than in general overweight/obesity (4.09 [OR 95% CI=2.57-6.51]) versus 1.83 [OR 95% CI=1.83-4.30]). The OR for HBP was higher when general overweight/obesity and abdominal obesity were clustered (OR=4.35 [OR 95% CI=2.68-7.05]), than when identified by either general overweight/obesity or abdominal obesity alone (OR=1.32 [OR 95% CI=0.65-2.68])
Pereira *et al.*[60]	Brazil	470 adolescents, aged 10-14 years	Cross-sectional	To evaluate the extent of dyslipidemia and investigate its association with overweight and abdominal obesity in adolescent	Adolescents who were overweight or who had abdominal obesity presented higher levels of TG and lower levels of HDL-C (P<0.05)
Goldbacher *et al.*[61]	Pittsburgh	211 adolescents between the ages of 14 and 16 years	Cross-sectional	Examined the association between central adiposity, measured by WC, and cardiovascular reactivity to stress	Independent of BMI, race, and gender, participants with a greater WC exhibited greater SBP reactivity and DBP reactivity (boys only). Race did not affect the results. Results from the present study suggest that central adiposity is associated with BP reactivity early in life, especially in adolescent boys

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Table 1: (Continued)

Reference	Location	Population studied	Type of study	Aims	Findings
Xu *et al*.[62]	China	8898 Chinese children (4580 boys and 4318 girls) aged 7-13 years	Cross-sectional	Explore the association of hypertension with obesity, metabolic abnormities including dyslipidemia, hyperglycemia, hyperinsulinemia, and MS among Chinese children	The prevalence of hypertension among abdominal obese children was higher than their counterparts (27.9% versus 8.4%, OR=4.6, 95% CI=3.8-5.5)
Al-Sendi *et al*.[63]	Bahrain	504 Bahraini school children aged 12-17 years (249 boys and 255 girls)	Cross-sectional	Examine the relationship between body composition and BP	Adolescents with high WHR or WC, as indicators for CO, tended to have higher BP values
Chen *et al*.[64]	China	19,593 children, aged 6-18 years old	Cross-sectional	Assess the prevalence of MS related components, and their association with obesity	Study showed that CO was more closely associated with MS than general obesity. Its associations with the other individual MS components (studied as continuous or categorical outcomes) seemed to be stronger than those with general obesity [Table 2] except for a few variables. Thus, data from this large sample of Chinese children support that CO indicates greater risk than general obesity. What is worth of noting is that most (81.0%) of the obese children had both general and CO. Thus, when it is difficult to measure both WC and BMI, measuring WC will be acceptable to identify pediatric patients at risk of MS related disorders, and it may be more cost-effective than measuring BMI
Boyraz *et al*.[65]	Turkey	451 pubertal children and adolescents aged between 8 and 18 years	Cross-sectional	Determine the prevalence of MS and frequency of metabolic risk factors in pubertal obese children, and to evaluate the relation between MS and plasma leptin levels	Coefficient correlation between WC (cm) and leptin (ng/ml) was r=0.213 and P<0.001
Maffeis *et al*.[66]	Italy	818 prepubertal children (ages 3-11 years)	Cross-sectional	Relationship between anthropometric variables, lipid concentrations, and BP and to assess the clinical relevance of WC in identifying prepubertal children with higher cardiovascular risk	WC had a higher correlation with SBP and DBP (r=5 0.40 and 0.29, respectively; P=0.001) than triceps (r=5 0.35 and 0.21, respectively; P=0.001) and subscapular (r=5 0.28 and 0.16, respectively; P=0.001) skinfolds and relative body weight (0.33 and 0.23 respectively; P=0.001). Multivariate linear model analysis showed that apolipoprotein A1/apolipoprotein B, HDL-C, TC/HDL-C, and systolic as well as DBP were significantly associated with WC and triceps and subscapular skinfolds, independently of age, gender, and BMI
Asayama *et al*.[67]	Japan	(102 boys and 75 girls) and control children (508 boys and 549 girls), ranging in age from 6±15 years	Cross-sectional	Determine the clinical utility of a new age-adjusted measure of body fat distribution (based on waist and hip circumferences) and stature, in relation to biochemical complications in obese children	The percentage overweight, percentage body fat, waist girth and WHR=height SDS all correlated well with TG, ALT and insulin in boys, whereas only waist girth and WHR=height SDS showed a close correlation with TG and insulin in girls
Agirbasli *et al*.[68]	Turkey	9-year-old children (n=1194)	Cross-sectional	Comparison of anthropometric indices in predicting MS components in children	Among covariates of SFT, BMI, WC, waist-to hip, or WHtR categories, the BMI category was the only significant predictor of having two or more MS risk variables OR=3.5, 95% CI=1.69-7.41, P=0.001 for boys and OR=4.7, 95% CI=1.61-13.55, P=0.005 for girls
Mesa *et al*.[69]	Spain	524 adolescents (265 males, 259 females, 15.3±1.4 years)	Cross-sectional	To explore in adolescents the associations between simple anthropometric variables with a continuously distributed summary score for lipid-related metabolic risk in both overweight and nonoverweight adolescents, and to test whether these associations are modified by the level of cardiorespiratory fitness	After multicollinear analysis and generalized linear modelling, suprailiac SFT in males (P=0.001, explained variance 12.2%) and WHtR in females (P=0.001, explained variance 10.0%) were the best determinants of the continuous metabolic risk score, after adjustment for age, sexual maturation, and economic status. These associations were slightly weakened in overweight males (P=0.034) and females (P=0.087)

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Table 1: (Continued)

Reference	Location	Population studied	Type of study	Aims	Findings
Gröber-Grätz *et al*.[70]	Germany	5.978 subject with 13.9±1.8 years	Cross-sectional	Investigate whether BMI or WC is a better predictor of hypertension or dyslipidemia in overweight/obese children and adolescents	Both BMI and WC are significant predictors of hypertension and dyslipidemia: BMI is a better predictor (OR=2.60) for hypertension than WC (OR=1.85), while WC (OR=1.90) was slightly superior to BMI (OR=1.86) in predicting adverse lipid profiles
Almas and Jafar[71]	Pakistan	1675 children aged 5-14 years	Cross-sectional	Investigate the relationship between WC and BMI with BP over a 2-year period, independent of the baseline BP	WC at baseline (β [95% CI=0.20 [0.13-0.29]), for each 1 cm increase) and change in WC from baseline to follow-up (0.24 [0.16, 0.34], for each 1 cm increase) were associated with increase in SBP. Similarly BMI at baseline (0.54 [0.33, 0.75] and change in BMI 1.32 [1.06, 1.59], for each 1 kg/m^2 increase) were associated with change in SBP
Leung *et al*.[72]	Hong Kong	6193 students (3074 boys and 3119 girls), aged 6-18 years	Cross-sectional	Determine the prevalence, risk factors for and patterns of hypertension in Chinese adolescents	High WC (□85th centile) was independently associated with a higher risk of hypertension (adjusted OR=2.4)
Ke *et al*.[73]	Australia	1232 9-year-old children	Cross-sectional	Investigate the relationship between obesity and high SBP in Southeast Asian and Australian children living in Australia	SBP increased by 1.51 mmHg for each unit increase in BMI for Southeast Asian children compared to 1.05 mmHg for Australian children. These SBP trends were also observed when WC and %TBF were tested [Table 2]. However, when stratified by obesity level, these differences were only observed in the "overweight/obese" BMI ranges (>18 kg/m^2) not in the "nonoverweight/nonobese" range. Stepwise regression modeling was undertaken to determine which obesity index was the strongest predictor of SBP: WC was found to the best predictor for SBP for Southeast Asian children (*r*=0.52) and BMI for Australian (*r*=0.32) children
Genovesi *et al*.[74]	Italy	5131 children (5-11 years)	Cross-sectional	Assess the prevalence of hypertension, prehypertension, and transient elevated BP (TH) and their relationship with weight class and WC in an unselected population of Northern Italian children	Weight class and WC were significantly associated to an increased risk of falling into any of the hypertensive categories. In children with TH BP *Z* scores of the mean of the three subsequent measurements following the first screening were significantly higher than BP *Z* scores observed in normotensive children (*P*<0.001)
Hirschler *et al*.[76]	Argentina	625 children (318 boys) between 6 and 14 years old	Cross-sectional	Association between IR and anthropometric indices, including BMI, WC, WC=height, weight=sitting height 2, and WC=sitting height, and (2) compared the abilities of these five indices to identify children with IR	The AUC were as follows: WC¼=0.78-0.021 (95% CI=0.74-0.82), BMI¼=0.77-0.022 (95% CI=0.73-0.82), weight=sitting height 2¼ 0.76-0.022 (95% CI=0.72-0.81), WC=height¼ 0.67-0.027 (95% CI=0.62-0.72), and WC=sitting height¼ 0.67-0.27 (95% CI=0.62-0.72), indicating that BMI, WC, and weight=sitting height 2 were acceptable predictors for IR, whereas WC=height and WC=sitting height were fair predictors as the AUC were <0.7

WC = Waist circumference; DBP = Diastolic blood pressure; CO = Central obesity; MS = Metabolic syndrome; CI = Confidence interval; OR = Odds ratio; BMI = Body mass index; HBP = High blood pressure; CRP = Centralperipheral; STR = Subscapular to triceps; SUM = Sum of the four skinfolds; BFP = Body fat percentage; AUC = Areas under the ROC curves; PFT = Preperitoneal fat thickness; TG = Triglycerides; TC = Total cholesterol; ALT = Alanine aminotransferase; WHtR = Waist-to-height ratio; SBP = Systolic blood pressure; HDL-C = High-density lipoprotein cholesterol; ROC = Receiver operating characteristic; SAC = San Antonio de los Cobres; T1DM = Type 1 diabetes mellitus; T2DM = Type 2 diabetes mellitus; BP = Blood pressure; IR = Insulin resistance; HOMA-IR = Homeostasis model assessment-estimated insulin resistance; FPG = Fasting plasma glucose; IFG=Impaired fasting glucose; LDL-C = Low-density lipoprotein cholesterol; WHR = Waist to hip ratio; WSR = Waist-to-stature ratio; SDS = Standard deviation score; SFT = Skinfold thickness; IMT = Intima-media thickness; TH = Transient hypertension most common variables. All these studies were included in spite the different measuring methods that they had used.

The following cardio-metabolic risk factors were considered: Systolic hypertension, diastolic hypertension, prehypertension, transient hypertension, cholesterol, LDL-C, HDL-C, fasting blood sugar, insulin resistance, insulin dose per body surface, carotid intima-media thickness, and alanine aminotransaminase.

The design of this study, age range and ethnicity of participants, different risk factors, different methods used for measuring abdominal obesity, geographic area and different statistical analysis among studies complicated the comparison of the study findings.

DISCUSSION

In this study, the association of abdominal obesity in children and adolescents with cardio-metabolic risk factors was reviewed systematically. BP was the most common measurement among studies; most of them confirmed the association of abdominal obesity and elevated BP. Some studies showed that this association was stronger in boys than in girls.[20-22] In addition, the association of abdominal obesity with systolic hypertension was seen more frequently than with diastolic hypertension.[23,24] On the other hand, one study did not confirm this association.[25]

In a study, total body fat was a stronger predictor of elevated BP than visceral fat in children and adolescents.[26] Some studies presented that after adjustment for body mass index (BMI), cardio-metabolic risk factors were more prevalent in children and adolescents with abdominal obesity than in those with overweight and general obesity.[19,27,28]

Some studies documented the association of abdominal obesity in children and adolescents with abnormal lipid profile and fasting blood glucose (FBG).[6,29-31] Some other studies showed that the combination of abdominal obesity and generalized obesity was a stronger risk for elevated FBG and dyslipidemia than each type of obesity alone.[6,29-31]

In general, most studies have confirmed the association of central fat deposition in children and adolescents with various cardio-metabolic risk factors. However, controversies exist on the definition of abdominal obesity in the pediatric age group.

Different measuring methods and various indexes were used to determine abdominal obesity, e.g., WC, WHtR, and WHR, and documented different results.[17,34] Further longitudinal studies are necessary to determine the appropriate anthropometric measures in children and adolescents to predict cardio-metabolic risk factors.

A number of methods have been employed in the assessment of the distribution of regional fat, such as computed tomography and magnetic resonance imaging. Different cutoffs are used to define central obesity in the pediatric age group, e.g., the National Cholesterol Education Program Adult Treatment Panel III has proposed WC ≥90th percentile in this regard.[77]

Although visceral fat, that is, body adipose tissue located within the abdominal cavity around the visceral organs, can be accurately assessed by imaging techniques as computed tomography and magnetic resonance imaging, the routine use of these techniques are not feasible clinically.[78] BMI itself cannot differentiate between fat and fat-free mass. Therefore, an elevated BMI may not reliably reflect the accumulation of adipose tissue.[79,80] In addition, the recent increase in mean BMI of children and adolescents has been accompanied by an even steeper increase in WC.[81]

However, in children and adolescents, BMI is strongly related to growth and maturation, and is expressed as z scores or percentiles relative to age and sex.[82] In addition, BMI does not always relate to central obesity[83] and it cannot differentiate muscle mass from bone and fat mass.[84]

The limitations of these indexes, however, should be considered. For instance, WC is correlated with the amount of intra-abdominal visceral fat, which may be the most detrimental fat depot,[85] it is also associated with subcutaneous abdominal fat and with total body fat.[86,87] In addition, a recent study found that WHtR and BMI are more strongly associated with each other than with percentage of body fat, as determined by air-displacement plethysmography.[88] These associations emphasize the potential problems in using WHtR and BMI as indexes of abdominal and generalized adiposity, respectively. The interpretation of associations with BMI and WHtR is further complicated by the possible relation of disease risk to height,[89] which is in the denominator of both indexes.

Some investigators have suggested that, even if the predictive abilities of WHtR and BMI-for-age are similar, WHtR may be preferred as an indicator of obesity-related risk.[90,91] The concept of a large WC relative to height may be easier to explain than is the division of weight (kg) by the square of height (m^2), particularly for those accustomed to using pounds and inches. In addition, because WHtR varies only slightly by age and sex, it is not necessary to express measures as percentiles or z scores, relative to a reference population, as is the case for BMI. The calculation of WHtR is also simpler, requiring only the division of numbers in the same units. Furthermore, the possible use of a single cutoff (0.5) to identify adverse measures among both children and adults[90] would result in a simple public health message of keeping WC to less than half of the height.

In addition, although the reproducibility of WC measurements is high,[92] some investigators have found that it is lower than that of BMI.[88] This difference might limit the ability of WHtR in detecting small changes in obesity-related risk. Furthermore, WC has been measured at numerous sites between the lowest rib and iliac crest, and there are differences between the recommendations of the anthropometric standardization reference manual,[93] the World Health Organization, and the National Institutes of Health.[92] Small changes in the location of the waist measurement can alter associations with the risk factor measures[94-96] and possibly with disease risk.

CONCLUSION

Whatever the definition used for abdominal obesity and whatever the methods used for anthropometric measurements, central body fat deposition in children and adolescents increases the risk of cardio-metabolic risk factors. Therefore, more attention should be paid to abdominal obesity of children and adolescents both in clinical practice and in epidemiological studies.

AUTHOR'S CONTRIBUTION

All authors contributed in the study concept and design, assisted in literature review, and drafting the paper. All authors have read the final version of the paper and accept the responsibility for its content.

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